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Study of Multianode Photomultipliers for the electromagnetic calorimeter preshower read out of the LHCb experiment

The LPC/LHCb and Barcelona/LHCb Groups *)

Abstract

The LHCb experiment will study the CP symmetry violation in the system of the beauty particles. The detector is a 20 meters long spectrometer, to be installed on the proton-proton collider LHC. Of major importance for the level 0 trigger is the preshower of the electromagnetic calorimeter designed to discriminate between electrons, hadrons and photons. The preshower cells consist of a two radiation lengths lead sheet located between two plastic scintillator planes. The scintillation light is extracted with wavelength-shifting fibres. The best candidates to read out the light of the 6000 detector cells are multianode photomultipliers. The HAMAMATSU photomultiplier R5900-00-M64 has been studied and its responses in terms of gain, linearity, uniformity within and between the anodes and cross-talk between the channels are addressed in this document.

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1 Introduction

The calorimetric system of the LHCb spectrometer includes a preshower detector, located immediately upstream from the electromagnetic calorimeter (ECAL); its geometry is designed for a one-to-one correspondence with the ECAL towers. The preshower is meant for a double purpose; first, preshower information is used together with the information from electromagnetic and hadronic (HCAL) calorimeters for the level 0 trigger of the experiment. Each 25 ns, a decision is taken to retain the events, based upon the identification of high transverse energy (E_{\perp}) electrons, hadrons, photons or π^0 . The second motivation of the preshower is the improvement of the photons and electrons energy reconstruction in the calorimetric device.

The preshower consists of a two radiation lengths lead sheet located between two squared plastic scintillator planes, of 6000 cells each. A detailed description of the preshower is given in [?, ?]. The scintillator signal is extracted with wavelength-shifting fibres. The best candidates to read out the light of the 6000 detector cells are multianode photomultipliers. The main characteristics of the preshower signal together with the requested performance of the specifically designed front-end electronics signal read-out are described in [?, ?]. This document concentrates on the photomultipliers performance for the preshower purposes, evaluated on a dedicated test bench. The HAMAMATSU photomultipliers(R5900-00-M64 [?]) has been studied and its responses in terms of gain, linearity, uniformity within and between the anodes and cross-talk between the channels are addressed in this document. The purposes of the test bench are described in Section 2. Section 3 deals with the experimental setup and the results are displayed in the last Section.

2 Experimental setup

2.1 The light system

The test bench is equipped with a light system intended to mimic the signal issued from the scintillator detector instrumented with the wavelength-shifting fibre. A 3mm blue LED is triggered by a voltage generator which provides square signals of 5ns width and amplitudes up to

10 V. A plano-convex micro-lens of focal length 1.5 mm is set in front of the diode to produce a parallel light spot of 3 mm diameter. The light is then crossing an optical filter with a continuously variable optical density, designed to allow a complete coverage of the detector dynamics. A 5 mm diameter ball lens is set just after the filter to focus the light on a quartz optical fibre with an active core of 200 μm . Figure 1 shows the mechanical support of the whole optical system.

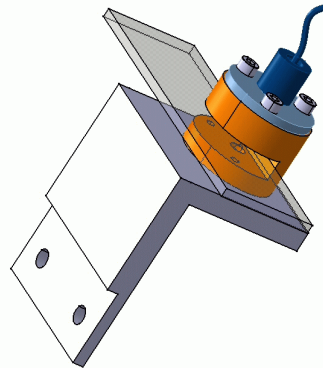


Figure 1: Mechanical design of the optical system support.

The light is then split with an optical coupling of ratio 1/2 and sent to the multi-anode PMT to be tested on one hand and a reference mono-anode PMT on the other hand, aimed at monitoring the light yield at the PMT window. The reference PMT is the HAMAMATSU R5900 used for the ATLAS Hadronic Calorimeter; it has been exhaustively studied and characterized in the past four years [?]. The total length of the optical fibre is 2 m.

2.2 The PMT translation table

The PMT to be tested is supported by a translation table allowing displacements of the PMT in a plane. The sketch of the support system of the PMT is displayed Fig. 2.

This system allows to move the PMT in front of the optical fibre, set at a distance of 100 μm from the PMT window, in order to perform the measurement of the anode uniformity. Two motorisations, monitored by Labview through a VME crate, govern the translations. The displacement resolution of the motorisations is 8

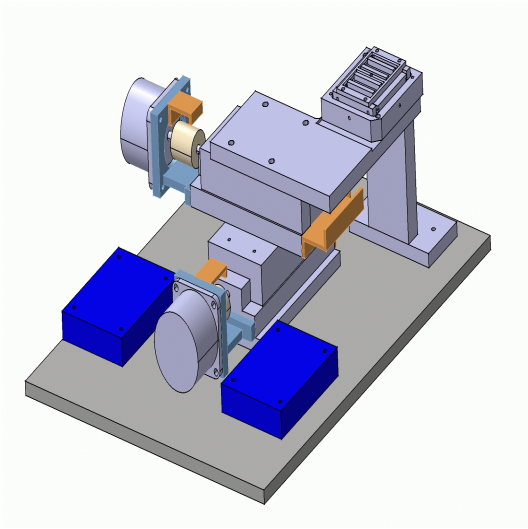


Figure 2: The planar translation table and the mechanical support system of the PMT.

μm in the two dimensions, allowing fine structure tests of the PMT response within one pixel.

2.3 Protocols and checks

For the purpose of the test bench, it is necessary to produce a light signal close to the detector one. That is realised with a 3mm blue LED supplied by a voltage generator based on mercury relays which is yielding a 5 ns square signal up to 10 V. The luminosity of the LED is 600 mCd. The LED light mimics satisfactorily the actual detector signal.

The PMT signal is acquired and digitalised by a 12 bits charge ADC. In order to interpret the response, the charge distribution is fitted with a normal law and its mean value and spread are extracted. The number of photoelectrons governs the spread of the distribution and can be expressed as:

$$N_{\gamma-e} = \langle Q \rangle^2 / \sigma_Q^2.$$

The constant correction due to the noise contribution depending upon the applied HV is not taken into account. This noise factor is estimated to be around 15%. The statistical uncertainty of this measurement is measured to be less than 10%.

3 Measurements

3.1 Gain measurement

The gain is measured by varying the PMT HV supply for a given attenuation of the light that corresponds to the linear range of the response over the whole variation of the HV. The data can be satisfactorily fitted with a power law $\langle Q \rangle = \alpha V^\beta$. The gain G is derived from the measured average charge through the relation :

$$\langle Q \rangle = N_{\gamma-e} \times G \times e.$$

The number of photoelectrons is measured at each HV point. The measurements are stable apart in the region of low voltages for which the collection efficiency at the first dynode begins to fluctuate. As a consequence, the number of photoelectrons used to derive the gain is the average of the measurements performed for the high values of voltages. Figure 3 shows the gain measurements at each HV value. Superimposed is the fit with a power law to the distribution of gains. The typical HV for the LHCb preshower is 650 V; that corresponds for the channels of the photomultiplier considered so far to a typical gain of few 10^4 up to 10^5 .

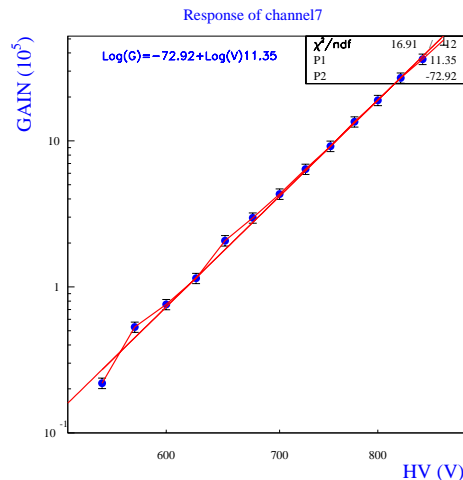


Figure 3: Gain measurements.

3.2 Linearity of the photomultiplier

The purpose of this measurement is to quantify the range of light yield for which the response of the PMT remains linear and compare it to the required dynamics for the preshower purpose. The

light is varied by means of the continuously variable optical density filter displacements and its yield is measured thanks to a reference PMT. An attenuation factor of few 10^{-4} is achieved. The stability of the optical coupling factor with the variations of the light attenuation has been checked with two reference PMT.

The PMT is assumed to be linear for the very high attenuations and its charge response is fitted in that range with a straight line. The deviation from the linearity law is computed for each measurement point through the ratio $(\langle Q \rangle_i - \langle Q \rangle_f) / \langle Q \rangle_f$, where $\langle Q \rangle_i$ and $\langle Q \rangle_f$ are the charge measurement and the fitted charge respectively. The light attenuation position is converted into the maximal current delivered by the PMT, which is the relevant quantity for the purpose of the comparison to the specification of the associated electronics. Figure ?? shows the curve of the deviation to the linearity as a function of the maximal anode current.

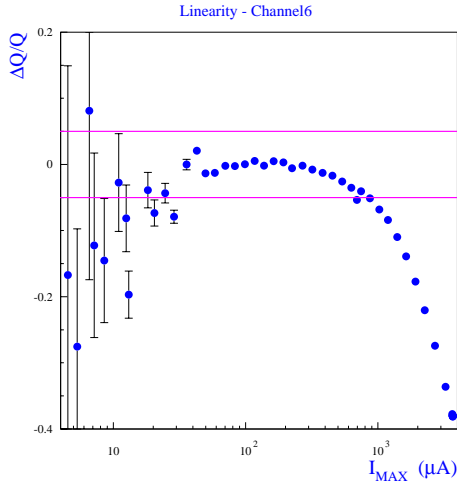


Figure 4: Deviation to a linear response of the PMT as a function of its maximum current delivered. The two straight lines show the deviations at the level of $\pm 5\%$.

For all the channels that have been scrutinized so far, a typical deviation to the linearity at the level of 5% is observed for a maximal current of about 1 mA. This value corresponds to the upper range of the preshower dynamics and the corresponding design of the very front-end electronics.

3.3 Anode uniformity measurements

The gain differences between the anodes of the MAPMT require to adjust the responses on the front-end electronics board, for instance with dedicated load resistors. An attempt to measure non-uniformities is performed with the light setup described Section 2. It shall be specified that these measurements cannot be used to derive the actual correction factors for the LHCb preshower; they deserve simply to qualify the intrinsic performance of the PMT.

The experimental protocol consists in moving the PMT in front of the optical fibre by step of 200 μm and read simultaneously the delivered charge on the fired anode. The light is attenuated in order to operate the PMT in a linear regime. It is observed that the pixels are set regularly and that the anode responses are qualitatively very similar for the inner pixels. However important border effects are observed with the effect of enlarging the useful surface of the pixel. A maximal non-uniformity factor (1:3) is observed.

Another study of interest is to scrutinize the response of one pixel. The PMT is there moved in front of the optical fibre with a step less than 100 μm to ensure a fine structure test. Figure ?? shows the typical answer of one anode - same structure was observed for all the instrumented anodes. The hollow in the middle of the pixel is due to the optical window split in two parts separated by a thin grid. It should be observed that the response is not symmetric with respect to the hollow. When the fibre is moved back to 1 mm in front of the optical window of the PMT, the hollow is washed out in average and the “useful” surface of the pixel is not a square anymore. This observation may serve also the design of the connexion light/PMT in the LHCb setup.

3.4 Electronic cross-talk measurements

The measurement of the cross-talk between the channels of the PMT is performed by reading simultaneously the eight neighbour channels of a fired pixel - the light is attenuated such that the PMT operates in the linear regime. Figure ?? shows the relative cross-talk in percentage. The size of the spot on the photocathode is estimated to be around 1 mm diameter. Those numbers

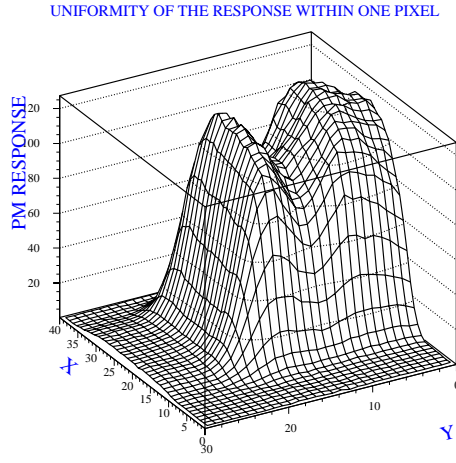


Figure 5: Typical response within one pixel.

refer as a consequence to the intrinsic electronic cross-talk between the channels. The diagonal cross-talk is negligible while the cross-talk with the adjacent cells is much less than the 1% level in average. Those results are perfectly satisfactory for the preshower purpose.

0	0	0.3	0.1
0	0.5	100	0.6
0	0.2	0.9	0.1

Figure 6: Distribution of cross-talk values in percentage.

4 Conclusions and perspectives

The multianode photomultipliers H7546 from Hamamatsu are candidates to read out the light issued from the cells of the LHCb preshower. A test bench for the study of their performance has been developed and is currently in oper-

ation. PMT responses in terms of gain, linearity, uniformity within and between the anodes and cross-talk between the channels have been scrutinized and are addressed in this document. Regarding these four points, the performance of the multianode PMT correspond so far to the PS specifications.

The main concern about the choice of these PMT is the stability of their performance in the LHCb operation conditions. The question of aging, related to the maximal average current at the anode, is the topic to be addressed in priority. The test bench will be used in the next future for that purpose.

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